International Journal of Civil, Structural,
Environmental and Infrastructure Engineering
Research and Development (IJCSEIERD)
ISSN(P): 2249-6866; ISSN(E): 2249-7978
Vol. 5, Issue 5, Oct 2015, 57-66

MACRO MECHANICAL PROPERTIES OF ULTRA HIGH PERFORMANCE CONCRETE USING GROUND GRANULATED BLAST SLAG AND NANO TITANIUM DIOXIDE

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ABSTRACT

Concrete is the predominant and most frequently used building material with a world wide annual material flow of 20-25 billion tons. Ultra high performance concrete (UHPC) is an emerging high-tech building material ,when compared to conventional concrete it allows more slenderness and increased durability in reinforced concrete structures. UHPC differs from conventional concrete because it consists of fine materials like quartz sand, quartz powder, silica fume. In this study , UHPC is produced with nano material to achieve target compressive strength more than 180MPa. Micro structural properties of concrete depends on curing regimes. In this, water curing and thermal curing is used. Cube specimens of size 70.6mm*70.6mm*70.6mm and cylindrical specimen of size 100mm dia*200mm high were cast and they are exposed to a temperature of 200˚c in oven for duration of 24, 48 and 72 hours at the age of third day followed with water curing till 28 days. Because of variation in nano material compressive strength ranges from 105 MPa to 185 MPa. From this study, it is observed that, nano material, quartz sand ,curing regimes affects the compressive strength and maximum compressive strength is achieved when 4% nano Titanium dioxide is used.

KEYWORDS: UHPC, Micro Structural, Quartz Sand, Quartz Powder, Nano Titanium Dioxide

INTRODUCTION

UHPC is generally characterized by its high silica fume content and low water cement ratio. At present, UHPC seems to be a promising material for special prestressed and precast concrete members. This is used for industrial and nuclear storage facilities. UHPC was developed in the 1990’s by Pierre Richard and Marcel Cheyrezy(1) at Bouygues laboratory in France. The sherbrooke bridge was the first UHPC structure which was constructed in Canada.

Recently, nano technology has attracted considerable scientific interest due to new potential uses of particles in nanometer(10^{-9} m) scale. F.de.Larrard et al(2) presented two models allowing to predict the packing density of a particle mix. Pierre Richard et al (3) studied that by elimination of coarse aggregates , optimization of the granular mixture allows the obtention of an homogeneous and dense cementitious matrix that exhibits high mechanical performances. Halit Yazici et al(4) developed UHPC by using pulverized flyash(FA), pulverised granulated blast furnance slag(PS),silca fume(SF) with the incorporation of Portland cement. J.K.Dattatreya et al (5) stated that particle packing density deals with the problem of selecting appropriate sizes and proportions of particulate materials to obtain a compact mixture. A.Cwirzen et al (6) studied the basic mechanical properties, frost durability and the bond strength with normal strength concretes of the ultra high strength mortars and concretes. E.Ghafari et al (7) presented an accurate analytical model, based on statistical

mixture design (SMD) approach, to evaluate the different level of replacement of the cement in UHPC. Ahmed Tafraoui et al(8) stated that silica fume have characterstics that make them exceptional in cement matrices in UHPC. Janis Justs et al(9) studied effect of pressure application to a fresh concrete right after casting and during the first 24 hours of hardening . Halit Yazici et al(10) studied the mechanical properties (flexural strength, compressive strength, toughness and fracture energy) of steel microfiber reinforced reactive powder concrete(RPC) with different curing conditions. Ali Nazari et al(11) investigated the compressive strength and workability of concrete by partial replacement of cement with nano-phase TiO_2 particles. Jun Chen et al(12) investigated nano TiO_2 effects on the hydration and properties of hydrated cement paste. Two types of nano-TiO_2 particles (Anatase and Rutile) were blended into cement pastes and mortars. Chong Wanget et al(13) studied UHPC preparation with ground granulated blast furnace slag, limestone powder. Tao Meng et al(14) studied effect of nano TiO_2 on the mechanical properties of cement mortar. Anjan kumar studied the performance of RPC without quartz powder and used fly ash and GGBS. Prem et al(15) investigated to identify an efficient curing regime for UHPC to achieve a target compressive strength more than 150MPa. Tina Oertel et al(16) used Amorphous silica particles in UHPC to densify the microstructure and accelerate the clinker hydration. Souradeep Gupta et al(17) presented the possibility of using two admixtures to develop UHPC to rip the benefits of reduced cost and enhanced sustainability.

From the previous studies, they used different types of steel fibers, limestone, flyash and stated importance of curing regimes. During the production of cement carbondioxide is released, it causes global warming. Main aim is to reduce cement content so, cement is replaced with GGBS Since target compressive strength is not achieved, nano material is used in UHPC mix.The main objective of this study are: to produce UHPC of compressive strength more than 180MPa, UHPC mixes are designed by variation in GGBS content and nano material.

MATERIALS AND THEIR PROPERTIES

Materials used for preparing UHPC mixes are Cement, Silicafume, GGBS, NanoTiO_2, quartz sand, quartz powder, steel fibers, super plasticizer and water. Zuari 53 grade ordinary Portland cement is used , it conforms to IS 12269-1987. Specific gravity of cement is 3.14. The initial setting time is 160 min and final setting time is 210 min. GGBS is white in colour in powder form confirming to IS 12089:1987. Specific gravity is 2.9. It is brought from JSW cement, Hyderabad. Properties of GGBS are given in Table2. Nano titanium dioxide is in the form of white powder. Particle size is 5 to 10nm. It is procured from sigma company, Hyderabad. Silicafume used is confirmed to ASTM C1240 and IS 15388:2003. Silicafume is brought from Astra chemicals Ltd, Chennai. Properties of silicafume are mentioned in table3. Quartz powder is in the form of white powdered quartz flour. Quartz powder is brought from Sriya sai bricks, dinnedevarapadu, Kurnool. Specific gravity is 2.6 and particle size ranges from 10 to 45μm. Quartz sand is in the form of yellowish white high purity silica sand. It is brought from Sathya narayana minerals, Kodumur, Kurnool. Quartz sand used are Grade1(particle size ranges from 300μm-150μm), Grade2(particle size ranges from 600μm -300μm), Grade3(particle size ranges from 1180μm-600μm). Specific gravity is 2.62. Hook end steel fibers are used with aspect ratio of 67 having dia of 0.45mm and length of 30mm. It is brought from Duraflex steel fibers reinforcement procured by Kasturi composite pvt Ltd, Amaravathi, Maharastra, India. Since in UHPC, w/c ratio should be less so high range water reducer is used. To increase strength, water content should be reduced. Master Glenium sky 8233 formely B-233 which is poly-carboxylic ether based superplasticizer is used. It is brought from BASF India Ltd construction chemicals –Secundarabad. Properties of superplasticizer are mentioned in table5. Master Glenium sky 8233 formely B-233 which is poly-carboxylic ether based superplasticizer is used. It is brought from BASF India Ltd construction chemicals –Secundarabad. Properties of

superplasticizer are mentioned in table3

Table 1: Properties of Cement

Slno.	Physical Properties	
1	Specific surface m²/kg	290
2	Normal consistency %	27
S.No	**Chemical Properties**	
1	Loss on ignition (%)	1.22
2	Insoluble residue (%)	1.12
3	Magnesia (%)	1.53
4	Lime saturation factor	0.95
5	Alumina iron ratio	0.83
6	Sulphuric anhydride(%)	1.86
7	Alkalies(%)	1
8	Chlorides (%)	0.01
9	C_3A (%)	6.5

Table 2: Properties of GGBS

Sno.	Characterstics	Requirement As Per BS:6699	Test Result
	Chemical Requirements		
1	Fineness (m²/kg)	275(min)	440
2	Insoluble residue(%)	1.5(max)	0.20
3	Magnesia content(%)	14.0	7.32
4	Sulphide sulphar(%)	2.00	0.25
5	Sulphite content(%)	2.50	0.22
6	Loss on ignition(%)	3.00	0.10
7	Manganese content(%)	2.00	0.05
8	Chloride content(%)	0.10	0.01
9	Glass content(%)	67	94.5
10	Moisture content(%)	1.00	0.10
11	**Chemical Modulus**		
A	$CaO+MgO+SiO_2$	66.66	79.41
B	$CaO+MgO/SiO_2$	>1.0	1.21
C	CaO/SiO_2	<1.40	1.01

Table3 Properties of Silicafume

S No.	Properties	
1	Form	Ultra fine amorphous powder
2	Colour	White
3	Specific gravity	2.63
4	Pack density	0.76gm/cc
5	Specific surface	20m²/g
6	Particle size	15µm
7	Sio_2	99.89%

Table4 Properties of Superplasticizer

S No.	Properties	Glenium B-233
1	Type of SP	Polycarboxylic ether
2	Appearance	Light brown
3	PH value	≥6
4	Specific gravity	1.08
5	Solid content	Less than 30% by weight
6	Chloride content	<0.2%

EXPERIMENTAL PROGRAMME

Mix Proportion

As there is no mix design for UHPC, mix design is referred from literature. From previous papers, it is observed that silica fume/cement ratio is 0.25 and quartz powder/ cement ratio is 0.4. The optimal dosage of steel fibers ratio is 2% by volume or about 155kg/m^{3}.Quartz sand is used as filler and super plasticizer is added in mix to provide workability. Mix proportions of UHPC mix with variation in GGBS and variation in nano material are mentioned in table5 and Table6 respectively.

Table 5 Mix Proportion of UHPC with Variation in GGBS

Mix	10% GGBS	20% GGBS	30% GGBS
Material	Kg/m^3	Kg/m^3	Kg/m^3
Cement	675	600	525
GGBS	75	150	225
Silicafume	187.5	187.5	187.5
Quartz powder	300	300	300
Quartz sand	857.4	782.4	707.4
Steel fibers	156.2	156.2	156.2
Super plasticizer	11.25	11.25	11.25
Water	187.5	187.5	187.5
w/c	0.2	0.2	0.2

Table6 Mix Proportion of Uhpc with Variation in Nano Material

Mix	0% Tio_2	1% Tio_2	2% Tio_2	3% Tio_2	4% Tio_2	5% Tio_2
Material	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
Cement	750	750	750	750	750	750
Nano TiO_2	0	7.5	15	22.5	30	37.5
Silicafume	187.5	187.5	187.5	187.5	187.5	187.5
Quartz powder	300	300	300	300	300	300
Quartz sand	932.4	932.4	932.4	932.4	932.4	932.4
Steel fibers	156.2	156.2	156.2	156.2	156.2	156.2
Superplasticizer	11.25	11.25	11.25	11.25	11.25	11.25
Water	187.5	187.5	187.5	187.5	187.5	187.5
w/c	0.2	0.2	0.2	0.2	0.2	0.2

Mixing Procedure

- A pan mixer machine (40 kg capacity) is used to mix UHPC.
- Dry ingredients i.e cement, quartz powder, silicafume are placed in the mixer and mixing is done for 3 minutes. Nano titanium dioxide is stirred by mixing 10% of water at high speed (120rpm) for one minute and it is added in the mix. Then quartz sand is added and mixed for one minute. Then 70% of water along with half of SP is added and mixed 2 minutes.
- When proper blending of ingredients is observed, remaninng SP and water is added and mixed for 3 minutes.
- When flowable consistency is observed, steel fibers are added slowly then mixing is continued for 2 minutes.

Specimen Preparation and Curing

For each mix, 12 cubes and 4 cylinders are cast. Size of cube is 70.6mm×70.6mm×70.6mm and cylinder size is 100mm dia × 200mm high. Cubes are placed in oven at temperature of 200˚c. After thermal curing for 24,48,72 hours they are placed in water till the date of testing.

Testing

Cubes and cylinders are tested for compressive strength and split tensile strength at 28 days respectively. They are tested under Compression testing machine (CTM) of 2000KN capacity. As per 363R-92[9.99] Modulus of elasticity(GPa) is calculated which is related to compressive strength(Mpa). Following expression is used ,

Theoretical Modulus of Elasticity = $3.65\sqrt{f_c}$

Where , f_c is compressive strength in MPa

RESULTS AND DISCUSIONS

As there is no standard mix design for UHPC mix proportion is designed by referring literature. Many factors influence strength of concrete such as thermal curing, nano material,duration of temperature, quartz powder, slilcafume.

Effect of GGBS on Compressive Strength of UHPC

Target mean strength is not achieved when GGBS is used. When GGBS content is increased,it is observed that strength is decreased. Maximum compressive strength is observed at 10% GGBS for samples which are thermally cured for 48 hours.

Table7 Compressive Strength of UHPC with Variation in GGBS

% Of GGBS	0%	10%	20%	30%
Normalwater curing	105.6	110	105	106
TC for 24 hours	135	139	140	135
TC for 48 hours	146	150	147	141
TC for 72 hours	150	135	140	129

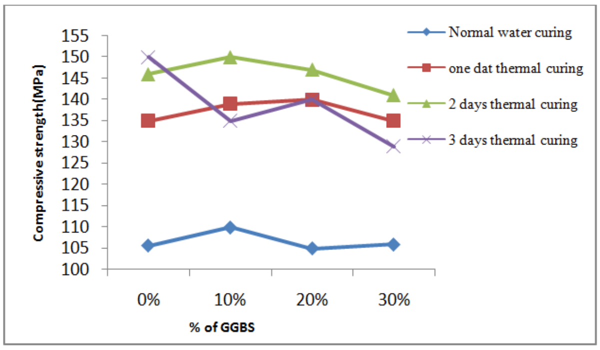

Figure 1: Variation of Compressive Strength versus % of GBBS

Effect of Nano Material on Compressive Strength of UHPC

Nano material effects comprise interparticle void filling, acceleration of cement hydration, formation of additional C-S-H by pozzolanic reaction, higher compressive strength, improved frost resistance, lower permeability. Nano TiO_2 do

not only fill in the voids left by the larger size particles, but by being highly reactive they react with calcium hydroxide and additionally act as nucleation sites for the production of very fine calcium- silicate- hydrate (C-S-H) phase. Small quantity of nano material is enough to increase its mechanical properties, if excess amount of nano $TiO_2$is used, it reduces compressive strength. Maximum compressive strength is achieved when 4% nano TiO_2 is used.

Table9 Compressive Strength of UHPC Mix In Mpa

% Of Nano Tio_2	0%	1%	2%	3%	4%	5%
Normal Water Curing	105	103	107	115	118	107
TC for 24 hrs	135	154	165	179	173	150
TC for 48 hrs	146	143	149	170	185	156
TC for 72 hrs	150	145	161	151	139	141

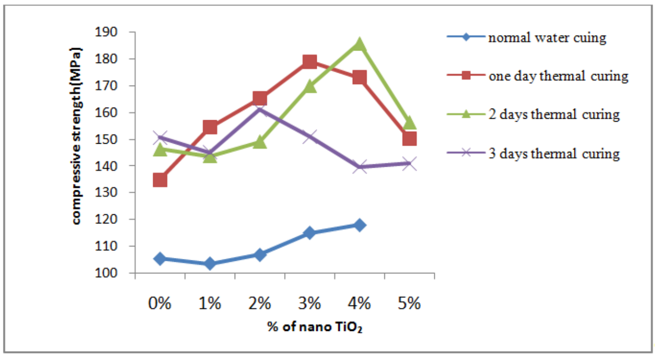

Figure 2 Variation of Compressive Strength versus % of Nano Tio_2

Effect of Quartz Powder on Compressive Strength of UHPC

Quartz powder act as a filler material at normal water curing and also it's act as a pozzalanic material at higher temperature.

Effect of Cuirng Regime on Compressive Strength of UHPC

Because of thermal curing, pozzalanic reaction of quartz powder, silicafume and nano material takes place.. If thermal curing is not done they just act as filler materials. In uhpc when the samples are palced in oven at temperature of 200˚c, Tobermorite, Xonotlite and Scawatite are formed and these are identified by SEM and XRD analysis . It is observed that maximum compressive strength is achieved for samples which are thermally cured for 2 days.

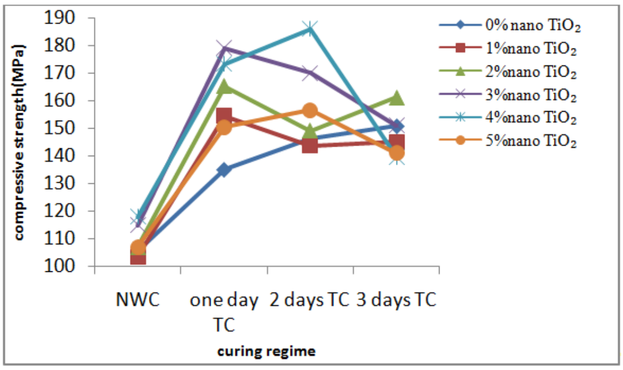

Figure 3: Variation of Compressive Strength versus Curing Regime

Split tensile strength resuits with varying nano material and different curing conditions are presented in table 9.

Variation of split tensile strength versus curing condition is presented in figure 4. It is observed that maximum split tensile strength is achieved at one day thermal curing with 4% nano TiO_2. Strength is increased at two days thermal curing followed by water curing.

Table9 Split Tensile Strength of UHPC Mix in Mpa

% Of Nano Tio_2	0%	1%	2%	3%	4%	5%
Normal Water Curing	13	12	13	12	13	11
TC for 24 hrs	14	14	15	16	19	14
TC for 48 hrs	14	15	16	16	18	16
TC for 72 hrs	15	14	12	17	14	13

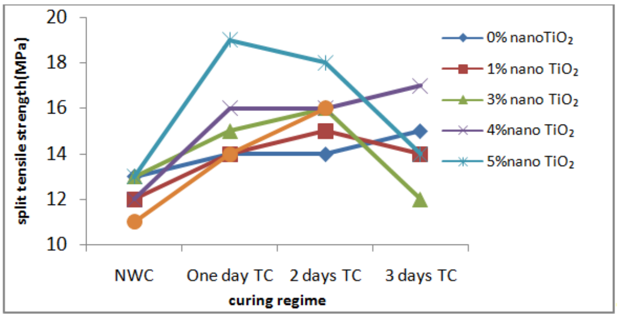

Figure 4: Variation of Split Tensile Strength versus Curing Regime

The theoretical modulus of elasticity results with varying nano TiO_2 and different curing conditions are presented in Table 10. Variation of theoretical modulus of elasticity versus curing regime is presented in figure 5. It is observed that two days thermal curing gives good results.

Table 10 Theoretical Modulus of Elasticity of UHPC Mix in Gpa

% Of Nano Tio_2	0%	1%	2%	3%	4%	5%
Normal Water Curing	37	37	37	39	39	37
TC for 24 hrs	42	45	46	48	48	44
TC for 48 hrs	44	43	44	47	49	45
TC for 72 hrs	44	43	46	44	43	43

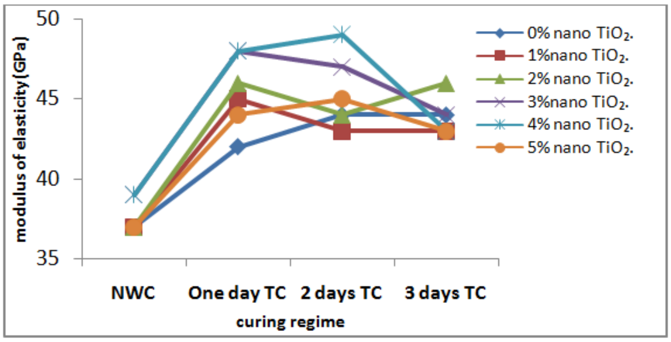

Figure 5 Variation of Modulus of Elasticity versus Curing Regime

CONCLUSIONS

From this study the following conclusions are given

- Ultra High Performance Concrete with compressive strength of more than 180 MPa can be produced using nano materials.
- Compressive strength of UHPC with 4% nano TiO_2 is optimum at 200^0C thermal curing in 48 hours. With increasing temperature from 150 ^{0}C to 200 ^{0}C the compressive strength increased and from 200 ^{0}C to 250 ^{0}C it decreased.
- The maximum compressive strength of 185 Mpa obtained for mix with 4% nano TiO_2 and 48 hours thermal curing at 200 ^{0}C
- The maximum split tensile strength of 19Mpa obtained for mix with 4% nano TiO_2 and 24 hours thermal curing at 200 ^{0}C
- The maximum Modulus of Elasticity of 49GPa obtained for mix with 4% nano TiO_2 and 48 hours thermal curing at 200 ^{0}C
- Maximum compressive strength, split tensile strength and Modulus of Elasticity attained at nano TiO_2 of 4% .
- It is observed that thermal curing regime increase the compressive strength up to 60 % that of normal water curing
- 48 hours thermal curing regime is sufficient and economical which improves the compressive strength significantly than 72 hours curing regime.
- Combination of thermal curing and normal water curing gives better results compared to only normal water curing.
- At normal water curing, pozzalanic reaction of silica fume and quartz powder is not activated, only they act as filler material
- Thermal curing regime activates the pozzalanic reaction of silica fume, quartz powder , nano material and micro structural changes of the hydrated structure

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